computers, special purpose computers, microprocessors, digital signal processors (DSPs) and multi-core processors.

[0069] While various exemplary embodiments have been described above it should be appreciated that the practice of the invention is not limited to the exemplary embodiments shown and discussed here. Various modifications and adaptations to the foregoing exemplary embodiments of this invention may become apparent to those skilled in the relevant arts in view of the foregoing description.

[0070] Further, some of the various features of the above non-limiting embodiments may be used to advantage without the corresponding use of other described features.

[0071] The foregoing description should therefore be considered as merely illustrative of the principles, teachings and exemplary embodiments of this invention, and not in limitation thereof.

[0072] The exemplary embodiments of the invention can be utilized in at least LTE-Advanced system Rel-13. In particular, the embodiments of the invention focus on LTE operation on unlicensed band aka LTE-LAA system which is currently under study in 3GPP (SID in RP-141664). It is widely assumed that LTE LAA operation is based on LTE Carrier Aggregation (CA) so that CA primary cell (PCell) remains on a licensed band while secondary cell (SCell) may locate on unlicensed spectrum.

[0073] It is noted that 3GPP rel-13 and beyond can include LTE/Wi-Fi aggregation technology where an eNB manages UE mobility but can utilize Wi-Fi as a second carrier for data transmission (Wi-Fi as data pump), for example to increase peak bit rate. The new use cases enabled include e.g., carrier aggregation, and complete network control of available resources and dynamic radio resource usage based on load and radio quality. LTE PDCP or even RLC is expected to be used on top of Wi-Fi stack multiplexing PDCP/RLC blocks over LTE and Wi-Fi radios and de-multiplexing received packets to form once again complete IP packets despite if both LTE and Wi-Fi are used. Another main alternative is to use Serving GW to distribute selected traffic over LTE access and other traffic over Wi-Fi access. This invention applies to all these scenarios.

[0074] In the following, we assume that LTE LAA applies a listen before talk (LBT) procedure based on European regulatory rules defined for 5 GHz ISM band, and that LTE LBT procedure fulfils the European regulatory rules defined either for frame based equipment or for load based equipment, discussed further in the following paragraphs. The scope of the invention is to reduce average latency of data transmission caused by LBT operation (or some other co-existence mechanism) in the LTE LAA context.

[0075] Regulatory Framework

[0076] Different regions have different regulatory requirements for unlicensed band operation. These are summarized in 3GPP Tdoc RP-140054 ("Review of Regulatory Requirements for Unlicensed Spectrum"). Despite of the regulatory rules, LTE has not yet been deployed in unlicensed spectrum.

[0077] In Europe, the regulations mandate the equipment operating on unlicensed spectrum to implement LBT by performing Clear Channel Assessment (CCA) before starting a transmission, to verify that the operating channel is not occupied. ETSI document EN 301 893 defines European regulatory requirements for unlicensed 5 GHz band. It defines two of modes of operation: Frame Based Equipment (FBE), and Load Based Equipment (LBE). The key properties and the differences between these options can be summarized as follows:

[0078] Frame Based Equipment:

[0079] Frame based equipment is the equipment where the transmit/receive structure is not directly demand-driven but has fixed timing. The corresponding European regulatory rules are defined in ETSI document EN 301 893 and can be summarized as follows:

[0080] LBT/CCA is performed periodically at predefined time instances according to a predetermined frame structure;

[0081] The periodicity (Fixed Frame Period)=channel occupancy time+idle period);

[0082] If the equipment finds the Operating Channel(s) to be clear, it may transmit immediately;

[0083] The total time during which an equipment has transmissions on a given channel without re-evaluating the availability of that channel, is defined as the Channel Occupancy Time (see the FIG. **3**);

[0084] If the equipment finds an Operating Channel occupied, it shall not transmit on that channel during the next Fixed Frame Period;

[0085] Equipment where the transmit/receive structure is not fixed in time but demand-driven.

[0086] FBE relies on a frame structure as given by frame based equipment operation and might suit better the LTE frame and the related carrier aggregation operation intended for LTE LAA. It is noted that operating FBE with a long fixed frame structure (e.g. 10 ms) might result in a low chance to find the channel unoccupied (low channel utilization) when co-existing with some LBE on the same carrier.

[0087] The fixed frame period consists of channel occupancy time (such as 1-10 ms for example) and idle period. The Idle period needs to be at least 5% of the channel occupancy time according to ETSI regulations. The device performs LBT periodically (the CCA has observation period) which lasts at least 20 μs (or at least 18 μs based on another specification version). If the equipment finds the Operating Channel(s) to be clear, it may transmit immediately. The total time during which equipment has transmissions on a given channel without re-evaluating the availability of that channel is defined as the Channel Occupancy Time. If the equipment finds an Operating Channel occupied, it shall not transmit on that channel during the next Fixed Frame Period.

[0088] Load Based Equipment:

[0089] Unlike for FBE, Load based equipment is not restricted to perform LBT/CCA according to a frame structure. Instead, LBE may perform LBT (CCA) whenever it has data to transmit. The key points can be summarized as follows:

[0090] Before a transmission or a burst of transmissions on an Operating Channel, the equipment shall perform a Clear Channel Assessment (CCA) check using "energy detect";

[0091] If the equipment finds the Operating Channel(s) to be clear, it may transmit immediately;

[0092] The total time that an equipment makes use of an Operating

[0093] Channel is the Maximum Channel Occupancy Time which shall be less than (13/32)×q ms, where q={4 . . . 32}. I.e. when q=32, the Maximum Channel Occupancy Time=13 ms;

[0094] If the equipment finds an Operating Channel occupied, it shall not transmit in that channel;